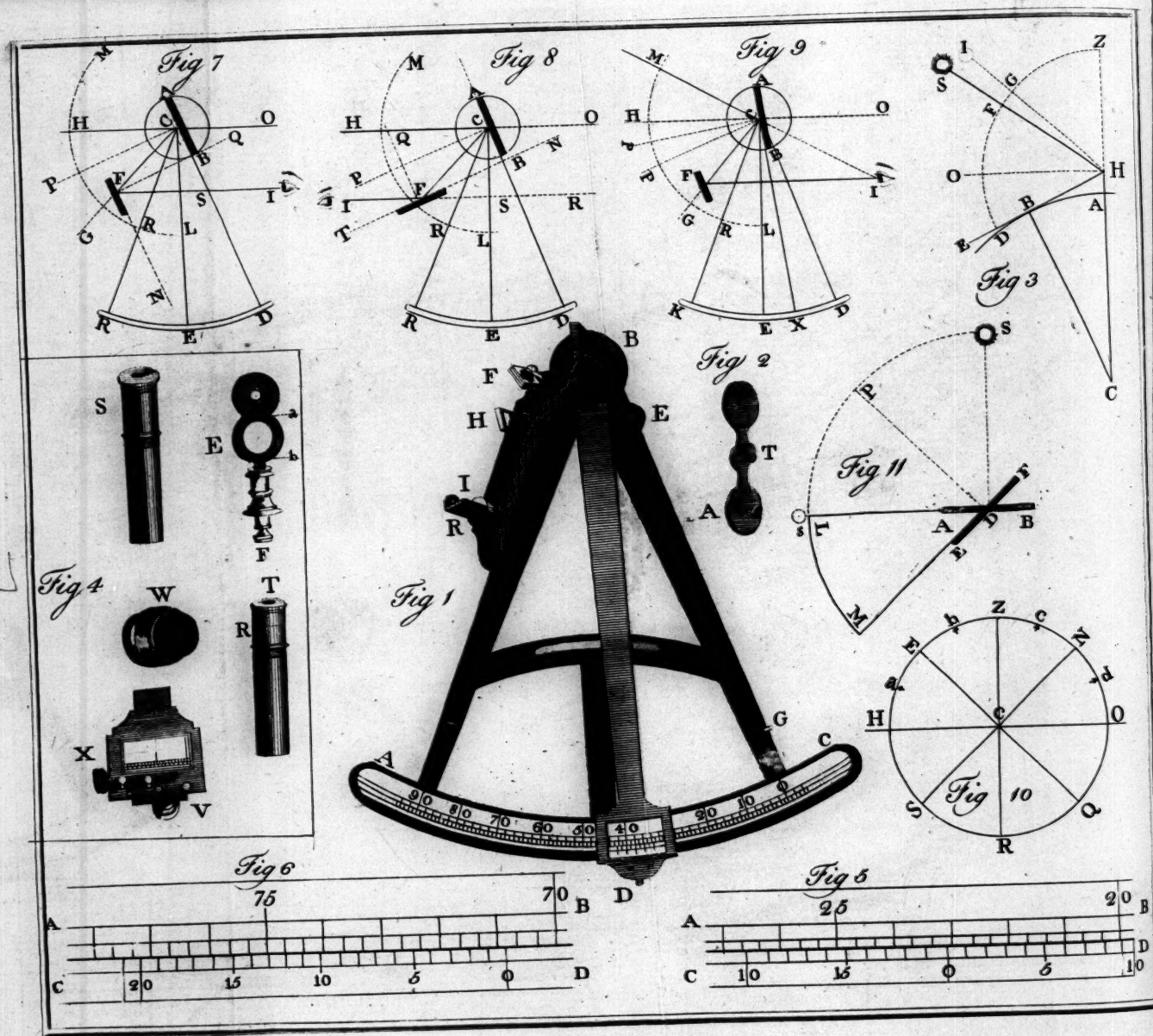
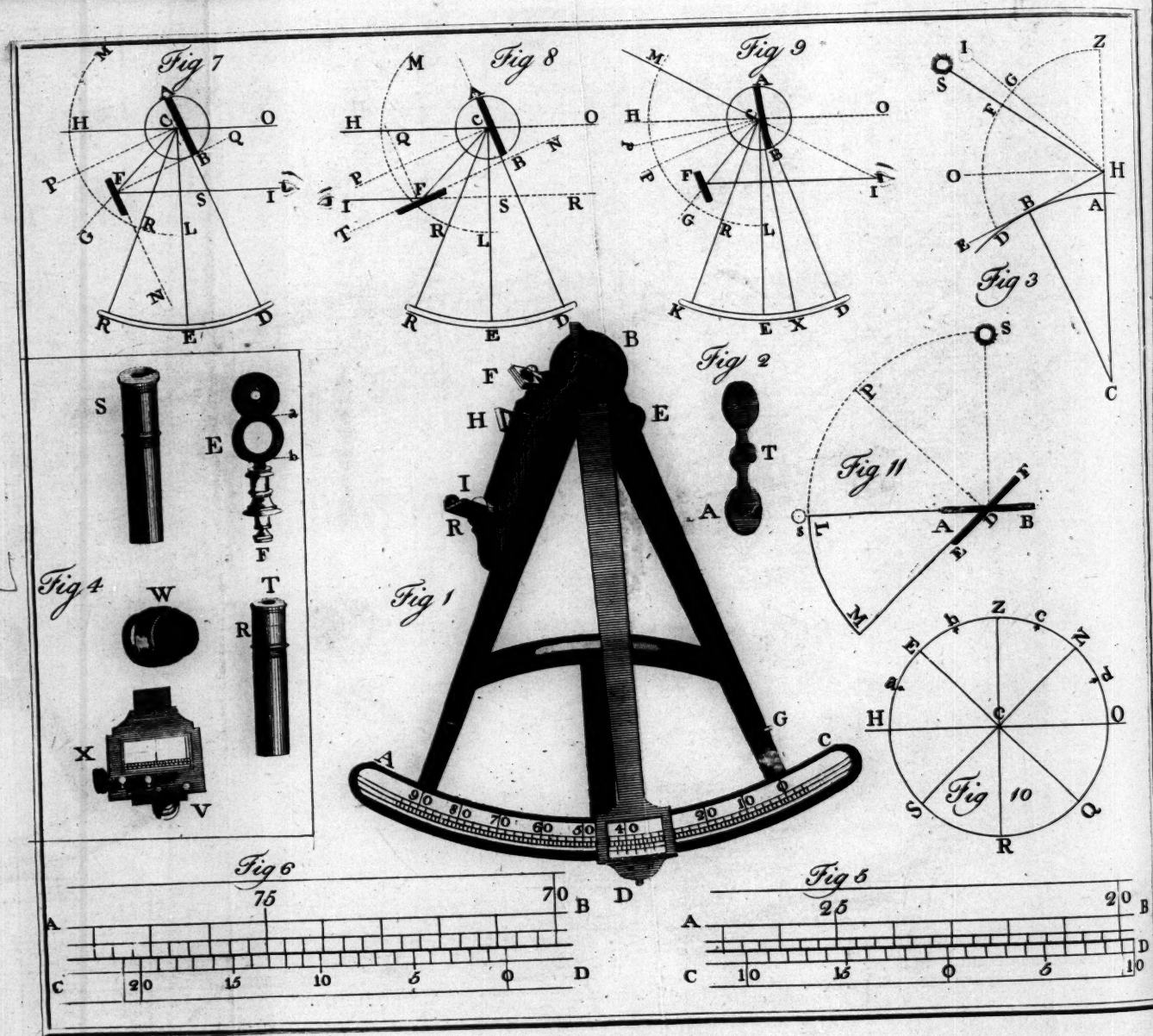






THE
DESCRIPTION AND USE
OF THE
SEA OCTANT,
COMMONLY CALLED
HADLEY'S QUADRANT;

WHEREIN

Its Use is exemplified by proper Examples and Tables,

AND AN ACCOUNT GIVEN OF THE

NEW ADDITIONAL APPARATUS

That are applied to it, for determining the Latitude and Longitude
with the greatest possible Accuracy.

TO WHICH IS ANNEXED,

A DEMONSTRATION OF THE THEORY

OF THIS

Excellent Instrument.

THE SECOND EDITION CORRECTED.

By WILLIAM JONES,
MATHEMATICAL INSTRUMENT MAKER.

LONDON:

Printed for and sold by W. and S. JONES, No. 135, Holborn. 1795*

[PRICE ONE SHILLING.]

DESCRIPTION AND USE

OF THE

HADLEY'S QUADRANT

BY

JOHN HADLEY, F.R.S.

AND

OF THE

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THE
DESCRIPTION
OF
HADLEY'S OCTANT.

THE invention of this valuable instrument is said to have arisen from J. Hadley, Esq. who made it public in the year 1731, by a paper then communicated to the Royal Society; and some writers upon the instrument have attempted to prove the invention to have been Sir Isaac Newton's, and others; but from Mr. Hadley's first publication of it, and his great abilities and particular skill in optics, there is no doubt but he was the original inventor of the instrument, and accordingly it has always borne his name.

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A Description of the OCTANT. See Fig. I.

A B C is a representation of the whole instrument, and is made in wood and brass, or all brass, from 4 to 18 inches radius, viz. from the center of B to the arc at D; about 16 inches is the radius, commonly made use of at sea.

The instrument consists of the following parts: 1. The index, B D. 2. The index glass on B. 3. The horizon glasses, H and R. 4. The dark-coloured screen glasses, F. 5. The sight vanes, E and I. 6. The adjusting levers and tightening screws on the back of the instrument, under the two horizon glasses, H and R; (See fig. 2.) where T denotes the tightening screw, and A the adjuster. 7. The arch, A C, of 90° (degrees); in some instruments this arch is continued to 120° , and something more; and from the frame then being the sixth part of a circle, is called *the Sextant*. This extension of the arch renders the instrument much more useful when large angular distances are to be measured.

The INDEX, B D, is a flat bar, moveable on the center of the instrument, and carries with it, round the center, the index glass; the part D, which slides over the graduated arch A C, is open in

the middle, containing a small divided piece, called the *Vernier*, by means of which, an angle may be measured to the accuracy of a minute of a degree. There is a tightening screw on the back of D, which serves to fasten the index at any situation on the arch. When the index is moved, it should be by the bottom part, and not the middle.

The INDEX GLASS on B is a flat square piece of glass, truly ground and polished, quicksilvered on the back, and fixed in a brass frame; behind it are two small screws that draw it up firm in its frame, and to the bottom of this upright plane is joined another brass plane perpendicular to it, by which all the brass work carrying the index glass is screwed down to the index. The use of this mirror is to receive the rays from the sun, or other object observed, and reflect them on the horizon glasses.

The HORIZON GLASSES, H and R, are two smaller portions of flat glass, truly ground and polished. The glass H is called the *fore* horizon glass, and the glass R, the *back* horizon glass, agreeing to the words *fore* and *back observation*, the meaning of which will be hereafter explained.

The lower half of the glass H is quicksilvered, the upper half left transparent, so that the edge of the sea, or other horizon, may be seen through it.

The glass R is silvered all over, except a transparent slip in the middle, through which the horizon is to be seen.

These two glasses are set in brass frames, similar to that of the index glass, and fixed on moveable bases, which are so adjusted by screws, as to set the glasses in their true positions.

The SKREENS, F, are coloured pieces of glass, truly ground and set in brass frames; they serve as a defence to the eye from the rays of the *sun* during the observation. When they are used for a fore observation, they are to be where the figure shews them; and when used for a back observation, to be placed below, between H and I. In the common quadrants two of these glasses are placed, but in the best finished, three, and sometimes four, and they are left easy in their cells, to move round when accurate observations are made.

The SIGHT VANES, E and I, are two pieces of brass, standing perpendicular to the plane of the instrument, in order to direct the eye properly to the horizon glasses. The vane E has usually two sight-holes; the under one for the better viewing the reflected image of the stars, or faint objects in the quicksilvered edge of the horizon glass H before it, and the upper one for viewing the reflected image of the sun, (when bright enough,) from the transparent part of the same glass.

The ADJUSTING LEVER, (fig. 2.) which is fixed on the back of the quadrant, and serves to move the horizon glasses to the utmost nicety by the adjuster A; when this lever is to be made use of, the screw T must be first loosened, then, when by the adjuster A the horizon glass is sufficiently moved, it is screwed fast again, and

and it will keep the lever from changing its position. In some instruments of the better kind this lever is moved by an endless screw.

The ARCH, A C, (fig. 1.) which is an *octant*, or the eighth part of a circle divided into 90° (degrees); each of these degrees is subdivided into three equal parts, each denoting $20'$ (minutes) or the third of a degree. The small divided scale in D, called the *Vernier*, made of box wood, ivory, or brass, is divided into a certain number of equal parts, usually 20, and it farther subdivides the arch into every minute ($1'$); therefore the motion of the index B D may be ascertained to the accuracy of a minute, or the 60th of a degree.

Before the learner proceeds to make any observation with the instrument, he must be perfectly acquainted with the nature of this *Vernier*; and if attention is paid to the following explanation, its nature and use will evidently appear.

Each degree, as before observed, is divided into 3 minutes, (See fig. 5, from 20° to the following divisions) therefore in 7 degrees there will be 21 minutes; then if on the piece of ivory, or *Vernier*, we take a length just equal to 7 degrees, and divide it into 20 equal parts, it is evident, that since 20 of these answer to 21 on the limb, each one of these will exceed each on the limb by $\frac{1}{20}$ th part, that is, by *one minute*; therefore 2 on the *Vernier* will exceed 2 on the limb of the quadrant by 2 minutes, 3 on the *Vernier* by 3 minutes, and so on: consequently, if the line marked O at the beginning of the divisions on the *Vernier*, be any where between two divisions on the limb, there will be a coincidence of one division on the *Vernier* with one on the limb somewhere; and by observing where that coincidence is, you will see at the same time how many minutes the index has passed the last division of the limb. Thus, if the coincidence be at the 3d division on the *Vernier*, it shews the index has passed the last division by 3 minutes; if the coincidence be at the 7th line on the *Vernier*, then is the index 7 minutes beyond the last on the limb, and so of the rest.

But to make this matter clearer, let A B (fig. 5.) represent a portion of the graduated limb of the quadrant, and C D, the *Vernier* on the index, placed appositely thereto, and in taking an observation, suppose the O, on the beginning of the divisions on the *Vernier*, be found between the 23° and $23^{\circ} 20'$, as in the figure; then looking for the first coincidence of lines on the limb and *Vernier*, you find it to be at the 6th division of the *Vernier*, therefore the angle is $23^{\circ} 06'$.

The two tens on the *Vernier* are the only two divisions that coincide at a time with the divisions on the arch, if the instrument is accurately divided.

If the first line or index of the *Vernier* has moved over a space less than half a division of the limb, then the coincidence will be on the

the right hand of O in the *Vernier*; if it has moved over more than half, it will be found on the left hand; if over just half, the coincidence will be at 10'. This shews the reason why the beginning O is placed in the middle of the *Vernier*, and not at the end; because in such a case you must look through all the divisions of the *Vernier* at once for the coincidence, whereas now we need but look over one half of them.

A more elegant and convenient mode of figuring the *Vernier* is now generally adopted in the best instruments; which is, by taking 20 divisions on the *Vernier*, equal to 19 on the limb, consequently one division on the limb will exceed one on the *Vernier* by $\frac{1}{20}$ th part, that is, by one minute; therefore the figures on the *Vernier* reckon all one way, *viz.* to the left hand. (See C D, fig. 6.) And to make this likewise clear, suppose the O, or beginning of the divisions on the *Vernier*, be found between $70^{\circ} 40'$ and 71° ; then looking for a coincidence of lines on the *Vernier* and limb, you find it to be at the 12th division of the *Vernier*; therefore the angle is $70^{\circ} 52'$, which is made by adding the 12' to the preceding $70^{\circ} 40'$.

Thus much for the description of the several component parts of the instrument: but previous to the directions for the proper methods of making observations, the learner must be well acquainted with the mode of adjusting the glasses of the quadrant; for should it come ever so perfectly adjusted from the maker's hands, it is liable to be put out of order by several accidental circumstances, *viz.* the warping of the frame from the sun's heat, straining of the parts that are only screwed, a fall, &c. Hence it is necessary that the mariner should be able to ascertain the error, and re-adjust the several parts before the observations are made.

The following are the particulars to be attended to, in the adjustment of the Hadley's quadrant.

1st. That the index glass be *perpendicular* to the plane, or surface of the quadrant; 2dly, That the *surface* of the fore horizon glass H be precisely *parallel* to that of the index glass, when the index is set at O, and the surface of the back horizon glass R perpendicular to the index glass, the index being at the same situation; or 3dly, The index error, which is no more than discovering at any time how much the horizon glasses are out of their proper position, when the index is set at O. This error is discovered in degrees or minutes by the index, and very frequently is attended to alone, in preference to the mode of adjusting the horizon glasses just observed.

First, To discover whether or not the index glass is perpendicular to the plane of the quadrant, you must hold the quadrant in an horizontal position, and bring the index glass near to your eye; look into it in a direction parallel to the plane of the quadrant, and see if the reflected arch appear exactly in a line with the arch seen direct by the eye, or that they make but one even plane, if so, the

the index glass is sufficiently upright, or perpendicular; but if, on the contrary, the arch and its reflected image appear inclined to one another, it shews that the index glass itself is inclined, and must be rectified by the screws which are on the base behind the glass; the outer screw is the regulating one, the others only steady screws, and by gently pressing the top of the glass, the way it inclines is easily discovered.

Secondly, To adjust the fore horizon glass H, the O on the *Vernier* of the index must be brought to coincide exactly with the O on the arch, which may be instantly done by bringing the index close to the button at G; then hold the plane of the instrument vertical with its arch downwards, look through the right hand hole in the vane E, and direct the sight through the transparent part of the glass H to the horizon, or edge of the sea. Now if the horizon line, seen both in the quicksilvered part and through the transparent part, should coincide, or make one straight line, the glass H is truly adjusted: but if one of the horizon lines stands above the other, slacken the screw T (fig. 2.) in the middle of the lever behind the glass, and turn the button A backwards or forwards, as there is occasion, until the horizon lines coincide, then fasten the screw T in the middle of the lever, and this horizon glass is adjusted.

The moon or the sun, if a dark glass is used before the eyes, will be better objects to adjust the glasses by; only you must particularly observe in this case, that when the index is at O, that the moon or sun by direct vision exactly cover the moon and sun by reflection, that is, neither higher or lower, and that they are not on one side of each other; if they should be on one side of each other, they may be brought exactly to join, by moving one of the screws on the base of H with a screw driver, taking care to tighten one as the other is slackened. These two adjustments may be made more exact if you look through the upper hole of the vane E, and take the reflection from the unsilvered part of the horizon glass, which is usually strong enough for this purpose.

To adjust the back horizon glass R, which is a glass never made use of at sea but when the horizon under the sun is too obscure to be well enough defined for an observation, or the interposition of land, then the observer turns his back to the sun, and looks through the transparent slit at the horizon. The method of adjusting this as well as the fore horizon glass, not being generally known to the mariner, is also another reason why it is neglected: but if attention is paid to the following directions, the mode of adjusting it will appear as clear as for the fore horizon glass.

Turn the button G on one side; find the dip of the horizon for the height of your eye above the water, by the table at the end of the book (as will be explained hereafter) and set the middle line of the *Vernier* as many minutes before O of the arch as there are
in

in twice that dip; hold the plane of the instrument vertically, with the arch downwards; look through the hole in the vane I, and if the horizon line seen through the transparent slit in the glass R coincides with the image of the horizon seen in the quicksilvered part of the same glass, then the glass R is in its proper position; if not, slacken the screw T, in the middle of the lever behind the glass R, and looking through the vane E, as before, turn the button G at the end of the lever backwards or forwards, as it is wanted, until the horizon lines coincide; then tighten the middle screw, and the glass R is adjusted. In setting this glass by the opposite horizon, the head should be held a little backwards, not to interrupt the light from behind. The horizon seen from behind will be inverted, that is, the water will appear above and the sky below. If the two horizon lines cross one another, the instrument is not held upright.---Another way of adjusting this shall be described in the method of making a fore observation.

Thirdly, Supposing the former adjustments were not attended to, to find simply the error of adjustment, called the index error. The method is, to turn the index of the quadrant until the sun, the moon, or any other proper distant object, appear as one, by the union of the image reflected with the object seen directly in the horizon glass; then the number of minutes by which O on the *Vernier* differs from O on the limb, is the error of adjustment, or the *index error*. If O on the *Vernier* stands between 0° and 90° on the limb, that is, on the quadrantal arch, then this error is to be subtracted from the angle or altitude shewn on the limb by the index: but if O on the *Vernier* stands on the other side of O on the limb, that is, on the small arch of excess, then the index error is to be added to the angle shewn on the limb.

Another way by which the index error may be more accurately determined, is by measuring the diameter of the sun;* to do which, the screens F must be put back, and then looking into the horizon glass H at the sun, you move the index, and bring the upper limb or edge of the sun to coincide, or just touch the lower edge: if it measures 32 minutes, there is little or no index error; but if it is less than 32 minutes, add the difference to any angle you measure, and, on the contrary, if it is greater, it must be subtracted from the angle. Or the sun's diameter may be measured twice with the index, placed alternately before and behind the beginning, or O, of the division; half the difference of these two measures will be the correction to be applied as just mentioned.

* In this method a dark glass, or slider of dark glasses, should be applied to the sight vane E, (fig. 1.) to screen the sun's rays from the eye.

*To take the Sun's Altitude by the Hadley's Quadrant.**I. By the fore Observation.—Fig. 1.*

FIX the skreens F above the fore horizon glass H, which are to be used separately or combined, according to the strength of the sun's rays, by turning the edges of their frames close against the plane or face of the instrument; then the face being turned towards the sun, hold the quadrant in your right-hand by the middle part of its frame, in a vertical position, with the arch downwards; put your eye close to the left-hand hole at E, (as the sun is generally bright enough to be seen from the unsilvered part of the horizon glass H;) now as you are towards the sun, look at the horizon through the transparent part of the horizon glass H, which is directly under the sun, then move the index at D forward with your left-hand till you see the red image of the sun come down and touch the horizon; if you do not find the red image readily, turn the skreens back, and you will then find it by its brightness, after which replace the skreens. The sun being thus brought to touch the edge of the sea with its *under* or *upper* edge, swing your body to the right and left, to try if the sun's edge glides along the horizon without cutting it, if it does, the observation is well made, and the *Vernier* on the arch will shew in degrees and minutes the altitude of that edge of the sun which was brought to the horizon.

If the lower edge, as is customary, was observed, 16 minutes, (the sun's semi-diameter) added to the said degrees, will give the altitude of the *center* of the sun; but if the upper edge was observed, the 16 minutes must be subtracted.

II. By the back Observation.

Set the index at O; place the stem of the skreens F into the hole next the horizon glass R, using them as before mentioned, according to the strength of the sun's rays; then turning your back to the sun, hold the instrument by the side next the horizon glasses in a similar position to the last, place your eye close to the hole in the vane I, and look for the red image of the sun in the quick-silvered part of the horizon glass R; then gently pull the index towards you, and move the quadrant until you have brought the upper or lower edge of the image to join or touch, as before, the horizon or edge of the sea; swing your body to the right and left, to try if the sun's edge runs along the horizon; if it does, the observation is well made, and the *Vernier* on the arch will give the altitude in degrees and minutes of that edge of the sun which was observed.

If the sun's lower edge was observed, then 16 minutes subtracted from the said degrees will give the altitude of the sun's

B

center;

center; but if the upper edge was observed, then 16 minutes are to be added, the reverse of the former.

The fore observation is of the two the more convenient, because there is a much larger scope above and below the altitude wanted, than in the back observation, which, on account of the obliquity of the index glass to the horizon glass, is more contracted in its use: and, indeed, the back observation should never be used when there is a clear horizon forwards, or under the sun, but only when it is hazy, ill defined, or intercepted by land; it is proper, therefore, that the horizon glass R should be always well adjusted: and because the former method is not readily attained by beginners, the following is given as one somewhat more convenient.

Another Method to adjust for the back Observation.

At any time when you have a clear horizon both for the fore and back observation, take the altitude of the lower edge of the sun by the fore observation as near to noon as can be, fix the index, then place the screens in the hole next the glass R, and turning immediately your back to the sun, look through the back sight vane I, and the open slit in the horizon glass R; then if the upper limb of the sun (in this observation it will appear to you the lower limb) appears to touch or sweep the horizon, the glass is adjusted: but if they do not touch, adjust it by the lever as before. Repeat this several times when the sun does not change his altitude very fast; thus your instrument will be nearly adjusted and ready for observation.

To take the Altitude of the Moon.

The moon's altitude may be taken either by the fore or back observation, exactly in the same manner as the sun's altitude; only in this case you bring that edge of the moon into contact with the horizon which is round and well defined, whether it be the upper or under edge. The corrections (hereafter mentioned) to be applied to the observed altitude of the moon are more numerous than for any other luminary, and every mariner should take care to provide himself with the *Nautical Almanack*, which contains a necessary collection of tables for the intended year.

To take the Altitude of a Star by the fore Observation.

The index being set at O, and holding the quadrant in a vertical position as before, direct the sight to the star through the horizon glass, and at the same time look for the reflected image of the star in the silvered part of the horizon glass; move the index a little, which will separate the reflected image from the direct image; the former will be easily distinguished from the latter by its motion when you move the index; continue to advance the
index,

index, following, at the same time, the reflected image of the star with your eye, directing the sight lower and lower, and changing the position of the quadrant as the star descends, till you have brought it to touch the horizon: the *Vernier* will then shew the observed altitude of the star.

If the altitude of the star is rather great, some other stars beside the one wanted may appear by reflection from the index glass on the horizon glass H; these will move about with the motion of the instrument, but the true star will remain at rest about the middle of the glass, so that the others cannot be mistaken for it.

An Account of the late Contrivances for improving the Methods of making Observations to the greatest possible Accuracy.

Within these few years Hadley's quadrants have been applied by the skilful mariner to take the observations necessary for finding the longitude at sea, it having been found that such observations required a degree of accuracy to which the instruments constructed in the common way were not competent: the mariner having complained of these defects, we have applied such sundry apparatus to the quadrants that in a great degree obviate the inconveniences complained of. The most material are as follow:

1. The graduation of the arch and *Vernier*, done by an engine of a new and peculiar contrivance, and by which we are enabled to divide instruments in general to greater accuracy, and particularly small instruments of no greater radii than 10 or 11 inches, into the exactness of 15" or 30" (seconds) of a degree.

2. A tangent screw to the lower end of the index, (see X in fig. 4) to regulate its motion, when brought by the hand to a division shewing nearly the contact required; and a magnifying glass, to read off the divisions shewn on the limb by the *Vernier*.

3. A small tube S, (fig. 4) instead of the sight vanes, to direct the line of sight parallel to the plane of the quadrant, which tube is to be screwed into a ring E, that is fixed to a square stem which slides in the socket made for the sight vane; and by the help of a screw under this, at the back of the quadrant, this stem may be raised and lowered, so as to move the axis of the telescope to point to any part of the horizon glass which is judged most proper for the observation.

4. To observe the contact of objects more accurately, a small achromatic telescope T is likewise fitted to the ring E; it magnifies about five or more times, and generally has fine parallel wires in the focus of the eye glass, that the contact of the objects may be observed in the middle between two wires; they divide the field of view into three equal parts; and when the telescope is adjusted parallel to the plane of the instrument, it will remain so during the observation. It draws out at R, in order to adapt it to the eyes of different observers, and to the different distances of the ob-

jects to the same observer. The telescope is adjusted by means of two screws, *a. b.*, placed on the ring E, the method of which will be described hereafter.

5. The arch has also been extended from an octant to a sextant, or the sixth part of a circle; by which means angles exceeding 90 degrees may be observed, and such angles are frequently wanted in taking the angular distances between the moon and sun, or moon and star; also, for the convenience of holding the instrument easily in such observations, a stout handle is fixed to the back, and is a very necessary addition. The instrument is made throughout of brass or other metal, and internally framed of different figures, according to the opinions of the maker, but the accuracy consists in good glasses, centering and dividing.

6. The index glass being liable in the common way of mounting to be bent, consequently the same observation would have different measures according as the object happened to be reflected from different parts of the index glass; this has lately been rectified by a new manner of setting the index glass in its frame.

7. Every glass mirror has two reflections, *viz.* one from the face, and one from the silvered back surface; these double reflections cause not only confusion among the reflected rays, but considerable errors in the observation, if the face and back of the glass are not parallel planes: and as none of these can happen from a plain mirror which has but one reflection, the upper part of the index glass is now made with its back rough ground and blacked; by which means the rays only that fall on its face will be reflected, and these are found sufficient when the object observed is tolerably bright; but when it is otherwise, the object may be observed from the lower part of the glass, which is silvered.

These several improvements are applied only to such quadrants and sextants as are considered of the best kind.

To adjust the Telescope.

The *axis* of the telescope is generally placed by the instrument makers as nearly parallel as possible, therefore it may be supposed to want no adjustment at sea; but the method of trying this may be done in the following manner: fix on any two distant objects, not less than 90 degrees asunder, (the sun and moon are very proper for the purpose) bring their nearest limbs into contact, by moving the index until they are reflected together; let this contact be at the wire *nearest* the plane of the instrument, (the telescope must be previously turned, so as to have brought the wires parallel to the plane) then altering the position of the instrument a *little*, bring the two objects to the wire *farthest* from the plane of the instrument: if the limbs are still in contact, the telescope is adjusted; if not, and the edges of the sun and moon lap over each other, it shews the object end of the telescope to be inclined from

from the plane of the instrument, and this must be rectified by unscrewing the lowest of the two screws, *b.* and *a.* (fig. 4) a little, and tighten the higher one, *a.*; if, on the contrary, the contact is observed at the uppermost wire, and when tried at the lower, they are separated, it shews that the uppermost screw, *a.* must be slackened, and the undermost screw, *b.* tightened. This operation being repeated, will render the means familiar, easy, and exact.

Underneath the ring *E*, which moves upon an axis, there is a screw *E*, which draws this ring and telescope nearer to, or moves them farther from, the plane of the instrument, in order to adjust the telescope nearly in a line with the edge of the silvered part of the horizon glass *H*.

For the adjustment by the sun, turn up the dark glass that is sometimes fixed behind the horizon glass, or instead of that, screw on the head of the telescope the wheel of dark glasses *W*, bring the index to *O* on the arch, look directly at the sun through the telescope, and move the index a little; then if the sun seen direct and the reflected image are both distinct, there needs no farther adjustment; but if one sun only appears, then, by means of the screw *F*, move the telescope nearer to or farther from the plane of the quadrant, till the two suns appear the plainest possible. Use the same method when you adjust by the moon, or a star, except in the dark glasses, which are in this case unnecessary.

The other adjustment is to fix the telescope in such a position as to see the image when the index may happen to be on any part of the arch of the quadrant or sextant. Proceed exactly as in the last adjustment, and bring the reflected image down till the index will move no farther; then if you do not lose sight of the reflected image, on account of the telescope pointing too high upon the horizon glass, it needs no farther adjustment: but if you lose sight of the reflected image, point the telescope lower, by turning the screw *F* underneath more towards the bottom of the horizon glass, till you see the reflected image to the greatest advantage. In moving the index through every part of the graduated arch, it may seldom be necessary to move the telescope upwards. This adjustment requires the person to be accustomed to observing with the telescope, otherwise he may easily lose sight of the reflected image, although the telescope be truly fixed.

To observe the Altitude of the Sun at Land by Reflection from Water, Quicksilver, &c.

The mariner when at sea has a most ready method of obtaining the altitude of the sun, moon, &c. by means of the horizon, or edge of the sea: but at land this is not the case; the inequality of the surrounding land, or other insurmountable objects, such as
build-

buildings, &c. entirely preclude the least conveniency of a natural horizon; therefore observers by land have had recourse to the means of taking their observations of the sun and moon from a reflection from the surfaces of fluids, such as water, quicksilver, &c. We frequently make particular apparatus for answering this purpose, called *Artificial Horizons*; they are of several different constructions, but the kind now generally adopted by the most expert observers is the following:

It consists of a shallow wooden trough, about four inches long and three inches broad, in which is placed quicksilver nearly up to the brim, this is placed on a steady basis, and to prevent the quicksilver from being agitated by the wind, a beveled roof fixes over it, having fixed in its sides two truly ground parallel glasses, quite transparent. The horizon being thus prepared, to make an observation by it, you bring the sun above in the sky to touch at their edges the sun seen by reflection in the quicksilver, with the quadrant as before; the number of degrees shewn upon the arch will be the *double* altitude, the half of which will give the true altitude of the sun at the place. When the tremulous motion of the quicksilver is too great, some observers have made use of water, treacle purified, &c. placed simply in the trough, without the glazed roof or covering.

Other observers find that a parallel glass rather of less dimensions than the trough, just placed upon the quicksilver afloat in the trough, will answer very well, and give a tolerable steady reflection: but these particulars depend upon circumstances, and little or nothing can be done without the place is steady, and then the first method mentioned does as well as the best. The mode of working an observation will be hereafter shewn by examples.

Before the rules are given for finding the latitude of the place, it will be necessary that the learner should be acquainted with the necessary corrections to be applied in taking the altitude of the sun, star, &c.

Corrections of the observed or apparent Altitude.

The first correction is for the sun's semi-diameter, as before observed; that is, if the under edge is observed, you add 16 minutes to the altitude taken; on the contrary, if the upper limb is taken, you must subtract the 16 minutes.

The second is for the *dip of the horizon*, which arises from the observer's eye being raised above the level of the sea, consequently he sees the horizon below the level of the *true* one, and the instrument must give an altitude too great when a fore observation is taken, and too small when a back observation, unless the latter of the two methods of adjusting the back horizon glass be used. As this error depends upon the height of the eye above the water, a table of these corrections to different heights is composed, and placed

placed at the end of this, which are to be subtracted from the altitude given: thus by the table it appears, that if the eye was 20 feet above the sea, that 2' 39" must be subtracted from the given altitude.

To explain this matter to the curious reader, let A B D (fig. 3) be a part of the surface of the sea, C the center of the earth, A C its semi-diameter, equal to 43,946,552 English feet; then if A H be any height to which your eye is elevated above the surface of the sea at A, and through the point H you draw H O perpendicular to H C, that line H O will be the *true horizon*; and if from the point H you draw the line H B to touch the surface of the sea in the same point B, then is the line H E the *marine horizon*, or that which appears to the eye. Lastly, the angle contained between the two, viz. the angle O H E, is called the *dip of the marine, or visible horizon*: wherefore, when the altitude of the sun or star at S is taken by the quadrant, the angle measured on the arch is S H E, greater than the true altitude S H O by the said dip or angle O H E, which therefore must be subducted from the measured altitude in the fore observation. The quantity of the dip or angle O H E is computed from the triangle B C H, right angled at B, in which the side B C is known, and also the side C H, when the height of the eye A H is given; the value in minutes the young trigonometrist may easily calculate.

The third correction is by reason of the refraction of light through the atmosphere, or body of air. The places of all bodies appear to be raised higher above the horizon than what they really are; so that suppose S (fig. 3) the true place of the sun or star, its apparent place will be at I, by this refraction of the air, and its angle or arch G D, which is measured by the instrument, and not the arch F E, is the real altitude above the sea; and therefore from the measured arch G D we subtract, on the one hand, the dip of the marine horizon O D, and, on the other, the arch F G, the quantity of refraction; and then we get the remainder F O for the true altitude required of the object at S.

A table of the corrections for the refraction of the heavenly bodies to be subtracted from the observed altitude is placed at the end of this book, where it appears, for example, that if the sun was observed to be 8° 50' high, that 5' 55" must be subtracted for refraction.

To find the Latitude of a Place by the meridian Altitude and Declination of the Sun, Star, &c.

The meridian altitude of the sun is the altitude taken at twelve o'clock at noon by the quadrant, and the tables subjoined give the declination of the sun for every day in the year at noon; then in the diagram (fig. 10) you observe the circle E N Q S is the meridian,

dian, $E Q$ the equator, $N S$ the earth's axis, $H O$ the horizon, $Z R$ the prime vertical.

Now the sun or star may be upon the meridian at (a), between the south part of the horizon H and the equator E ; or it may be at (b), between the equator E and the zenith Z ; or it may be on the north part of the meridian at (c), between Z and the pole N ; or at (d), between the pole and the horizon O ; it may also be on the equator at E , and in the zenith Z ; and so upon the whole there will be the following *six cases*, with regard to the latitude.

Case I. Let the meridian altitude be $H a$, which taken from 90° , leaves the zenith distance $a Z$; the declination $E a$ being south, subtracted from $a Z$, leaves $E Z$ the latitude of the place.

Case II. Suppose the sun in the equator at E , then its meridian altitude $H E$ taken from 90° , leaves the latitude $E Z$.

Case III. Let the sun have north declination at b , between the equator and zenith, then the declination $E b$, added to the zenith distance $b Z$, (or the altitude $H b$ less $E b$ taken from 90°) will give the latitude $E Z$.

Case IV. If the sun be exactly in the zenith Z , then its declination $E Z$ in the tables is the latitude of the place.

Case V. If it be between the zenith and the elevated pole at c , then the zenith distance $Z c$, subducted from the declination $E c$, leaves the latitude $E Z$.

Case VI. Let the sun be at d , between the pole and the horizon, then its meridian altitude $O d$ taken from its declination $Q d$, leaves $Q O$, the complement of the latitude sought, or 90 less the latitude.

To the unmathematical reader perhaps the following rules in words only may render the method more clear.

First, If the sun or star be south when observed, call the zenith distance south; but if north, call it north.

Then if the zenith distance and declination be of *contrary* names; that is, if the sun or star comes to the meridian of the north, and hath south declination; or to the south, and hath north declination, the zenith distance, *added* to the declination, gives the latitude of the place of observation; and of the same name the declination is, whether north or south.

Secondly, When the zenith distance and declination are of the *same* name; that is, when the sun or star comes to the meridian in the north, and hath north declination; or to the south, and hath south declination, subtract the lesser from the greater, and the remainder is the latitude: and to discover whether it is north or south, observe this rule—

When the declination is greater than the zenith distance, the latitude is of the same name with the declination; but if less, of a contrary name.

EXAMPLE

EXAMPLE I. Suppose at sea, on the 27th of May, 1788, the sun's meridian altitude was observed to be $57^{\circ} 35'$, and to the south of the observer, what was the latitude of that place?

Meridian altitude	—	$90^{\circ} 0'$ $57 35$
Zenith distance	—	$32 25 S$
Sun's declination in table for May 27, 1788, is	}	$21 27 N$
Latitude in		$53 52 N$

EXAM. II. Suppose at sea, on the 5th of Aug. 1789, the meridian altitude of the sun was $27^{\circ} 13'$ north of the observer, required the latitude in

Meridian altitude	—	$90^{\circ} 0'$ $27 13 N$
Zenith distance	—	$62 47 N$
Sun's declination in table for Aug. 5, 1789, is	}	$16 50 N$
Latitude in		$45 57 S$

EXAM. III. Suppose at sea, on the 14th of Jan. 1789, the sun's meridian altitude was observed to

be $72^{\circ} 17'$ south, what was the latitude of the place of observation?

Meridian altitude	—	$90^{\circ} 0'$ $72 17 S$
Zenith distance	—	$17 43 S$
Declination per table	—	$21 11 S$
Latitude in	—	$3 28 S$

In this case it appears that the observer was between the sun and the equator.

EXAM. IV. Suppose at sea, on the 4th of May, 1784, the bright star Fomalhaut, when on the meridian, was observed to be $37^{\circ} 21'$ above the horizon of the sea, and to the north of the observer, required the latitude of the place.

Meridian altitude	—	$90^{\circ} 0'$ $37 21 N$
Zenith distance	—	$52 39 N$
Fomalhaut's declination from the tables in the common navigation books	}	$3^{\circ} 44 S$
Latitude in		$83 23 S$

Examples wherein the foregoing necessary Corrections are applied both in the fore and back Observations.

EXAM. V. Suppose at sea, on the 15th of April, 1790, by a fore observation with the Hadley's quadrant, the sun's lower edge was found to be $40^{\circ} 20' S$. the eye being 30 feet above the sea, required the latitude.

Obs. alt. sun's lower edge	$40^{\circ} 20' S$
Semi-diameter to be added	$0 16$
App. alt. sun's center	$40 36 S$
Dip of hor. (per tab.) subtr.	$0 5$
App. alt. cor. by the dip	$40 31 S$
Refract. (per tab.) to be subtr.	$0 1$
True alt. of sun's center	$40 30 S$

True alt. of the sun's center	$40 30 S$ $90 0$
True zenith distance	$49 30 S$
Declination (per tab.) for ap. 15 9 55 N	$15 9 55 N$
Latitude	$59 25 N$

EXAM. VI. Suppose on the 31st of July, 1790, an observer 40 feet above the sea finds the apparent altitude of the sun's upper limb to be $56^{\circ} 22' N$. required the latitude of the place.

C

App

App. alt. sun's upper edge	56° 22' N
Sun's semi-diameter subtr.	0 16
	56 6 N
Dip of hor. to be subtr.	0 6
App. alt. corrected by dip	56 0
Refractor to be subtracted	0 1
True alt. of sun's center	55 59
	90 0
Zenith distance —	34 1 N
Sun's declination for 31 July	18 12 N
Latitude —	52 13 S

In this case the upper edge being observed, the semi-diameter is subtracted.

EXAM. VII. Suppose at sea, Nov. 27, 1790, by a back observation with the Hadley's quadrant, the apparent altitude of the sun's lower edge was 25° 12' S. and the eye 40 feet above the sea, in what latitude was the observation made?

Obs. alt. sun's lower edge	25° 12' S
Semi-diameter to be subtr.	0 16
	24 56 S
Dip for 40 feet to be added	0 6
	25 2 S
Refract, to be subtr. —	0 2
True alt. of sun's center	25 0
Zenith distance —	65 0 S
Declination for Nov. 27	21 15 S
Latitude —	43 45 N

The dip is added in the back observations.

EXAM. VIII. Suppose the eye of an observer, at 35 feet above the water, should with the fore observation by the quadrant find the altitude of the star Sirius

53° 35' S when on the meridian, required the latitude of the place?

Obs. alt. of Sirius	53° 35' 00" S
Dip of horizon subtr.	0 5 39
	53 29 21
Refraction to be subtr.	0 0 42
True alt. of Sirius	53 28 39
	90 0 0
True zenith distance	36 31 21 S
Declination from the navigation books } 16 25 0 S	
Latitude —	20 6 21 N

EXAM. IX. Suppose on Nov. 5th, 1788, being on land, and wishing to know the latitude of the place where I then was, I had taken the double altitude of the sun by reflection from water, quicksilver, or other artificial horizon, viz. by bringing the lower edge of the sun to touch the nearer edge of the reflection of the sun in the fluid, the Hadley's quadrant shewing the angle to be 44° 30' S. required the latitude?

Double altitude —	44° 30' S
Half of which gives the apparent altitude } Semi-diameter to be added	22 15 S
	0 16
	22 31
Correct. for refrac. —	0 2
True alt. of sun's center	22 29
	90 0
Zenith distance —	67 31 S
Declination per table —	15 59 S
Latitude (of London)	51 32 N

In this case there is no dip, as half the observed altitude gives the real altitude.

The Demonstration of the Theory of Hadley's Quadrant.

THE Theory arises from the *first principle*, or rather *axiom*, of OPTICS, *viz.* that in case of light falling on, or reflected from any polished surface, or speculum, *the angle of incidence is ever equal to the angle of reflection.*

This principle is demonstrated by *writers* on OPTICS, both from reason and experiment, and is easily illustrated by fig. 11. Let E F be a plain mirror, on which a ray of light S D falls in the point D; then if the line P D be perpendicular to the glass at D, and make the angle P D L = (equal to) the angle P D S, the line D L will be the *reflected ray*; and in all cases the *angle of incidence* S D P *will ever be equal to the angle of reflection* P D L.

If M D be an index fixed on the speculum in a line with its surface E F, it will then be in the direction D M, at right angles to the perpendicular P D; and supposing the incident ray S D reflected to L D, then by moving the index M D towards D L, the glass F E will have the same motion on the center D, and at last arrive at the situation A B; during which time the perpendicular P D will gradually approach to the incident ray S D, and at last coincide with it.

But as the perpendicular P D approaches the ray S D, the angle of incidence, P D S, is constantly decreasing, and therefore, also, the angle of reflection, P D L, which is always equal to it: and when P D coincides with S D, or D M with D L, then both these angles vanish, and the incident ray is reflected back upon itself, or in the same direction from D to S.

In the time the perpendicular P D moves through the arch P S, the reflected ray D L moves through the arch L S, which is double the arch P S. Therefore the motion of the reflected ray L D is *twice* as quick as the motion of the perpendicular P D, or of the index and its glass M D.

Now let A B of fig. 7 represent the index, or large glass of *Hadley's Quadrant*, moveable on the center C of the instrument by means of the index on which it is fixed, and let P C be perpendicular thereto in the point C; then if any ray of light, as H C, fall upon it in the point C, it will be so reflected as to make the angle of incidence H C P equal to the angle of reflection P C G; and therefore describing on the center C the circle M R L, and making the arch P G = P H, the line C G will be the reflected ray.

Again: let F be the smaller glass in a position F N, parallel to that of the larger one A B, and suppose F Q perpendicular thereto; then again, the ray of light C G falling on this glass, in the point F, will be so reflected, that the angle C F Q will be equal to the angle Q F I, if F I be the reflected ray.

Now because the two glasses A B and F are in a parallel position, therefore the perpendiculars P C and F Q will also be parallel, and the right line C F which crosses them will make the alternate angles P C F and C F Q equal; and consequently the angle

$\angle H C P$ will be equal to the angle $\angle Q F I$, which proves that the ray $F I$ after two reflections is parallel to the incident ray $H C$.

Hence, in all positions of the quadrant (while the glasses remain parallel to each other) the eye at I will view any very distant object in the same place by the reflected ray $F I$, as it would do by the incident ray at O if the glass $A B$ was removed. Hence the reason of adjusting the quadrant by a *distant object*, (either the horizon itself, or any other remote object) since in such a case, the object seen by the direct ray $H C$, and the image shewn by the reflected ray $F I$, do coincide, or appear in one and the same place.

But this is not the case when the object is so near that the line or distance $C S$ subtends at the object a sensible angle, because then the incident and reflected rays $H C$ and $F I$ intersect each other; and therefore the object and image in the glass at F will appear in two different places.

If the position of the small glass F (fig. 8) be perpendicular to that of the large glass $A B$, or $T F N$ perpendicular to $A B D$, and the line $Q F$ perpendicular to the said glass in F , then the angle $\angle H C P$ is equal to the angle $\angle P C F$ as before, and also the angle $\angle C F Q = \angle Q F I$; therefore the angle $\angle C F N = \angle F T I$: but $T N$ is parallel to $P C$, therefore the angle $\angle C F N = \angle F C P$, and also to the angle $\angle P C H$, consequently the angle $\angle T F I = \angle P C H$: but $T F$ is parallel to $P C$, therefore the reflected ray $I F$ is parallel to the incident ray $H C$; wherefore the image of an object at a great distance is seen at R by an eye at I , in the same right line with the object itself, but in an opposite part of the hemisphere; which gives the reason why the lowermost of the horizon glasses is placed in that position on the side of the quadrant for the back observation.

If while the glass F retains its position (as in fig. 7) the large glass $A B$ be moved on the index from its parallel position in $A D$ to any other, as $A X$, (fig. 9) then, while the index $C X$ describes the angle $\angle D C X$, the perpendicular $P C$ will describe the equal angle $\angle P C p$. In this situation of the glasses, let $M C$ be the incident ray, and $F I$ the last reflected one; produce $M C$ till it intersects the reflected ray at I : then will the angle $\angle M I F$ be equal to twice the angle $\angle D C X$. For in this case the angle by the first reflection is increased from $\angle G C H$ to $\angle G C M$, by the excess $\angle H C M$: but half the angle $\angle G C M$ is $\angle G C p$, and its excess above $\angle G C P$ (the half of $\angle G C H$) is the angle $\angle P C p$; therefore the whole excess $\angle H C M$ of the whole angle $\angle G C M$ above $\angle G C H$, must be equal to twice the angle $\angle P C p$, or twice the angle $\angle D C X$: but since $H O$ is parallel to $F I$, the angle $\angle M C H = \angle M I F$, consequently the angle $\angle M I F$ is equal to double the angle $\angle D C X$; therefore the angle $\angle M C H (= \angle M I F)$ is also double the angle $\angle D C X$.

Or thus: since the glass F is immovable, and also the point C , which is the center of the moveable glass $A B$, it is easy to understand that the rays $C F$ and $F I$ will each of them be fixed; and therefore the ray $C F$ may be considered as falling on the glass $A B$ in the point C , and thereby reflected in the direction

C M: but C M, considered as the reflected ray, has twice the motion of the reflecting glass A B, or its index A X; that is, while the index moves from D to X, the ray is reflected from H to M, and the arch H M is double the arch D X, as was shewed in the beginning was always the case in single reflection.

It now appears by demonstration, that by moving the index over any number of degrees on the limb of the quadrant, you measure an arch in the heavens just equal to twice that number of degrees; and therefore the *octant*, or *eighth part of a circle*, is by this construction rendered equivalent to the *fourth part* of a circle for measuring angles.

But the greatest advantage of this instrument, and by which it excels all others for sea use, consists in this, *that the image of an object by the second reflection is quiescent, or at rest, while the quadrant is in motion*: that motion is meant which is made in a vertical plane passing through the object; for let the instrument have what position it will in that plane, the angle M I F is not thereby affected or altered, and consequently the positions of the last reflected ray is the same, and therefore the apparent place or image of the object must necessarily be invariable or at rest.

To demonstrate this in the easiest way, we need only to consider, that as the quadrant moves on the point C, or axis of the glass A B, (fig. 7) the perpendicular P C will be carried to or from the fixed line H O, and thereby the angle P C H becomes diminished or increased; but the angle P C F will ever be equal to P C H: and because the perpendicular Q F is always in this case parallel to P C, therefore the angle C F Q is equal to P C F, and consequently C F I is always equal to F C H; therefore the reflected ray F I is parallel to H C constantly, and will of course shew the object ever in the *same place*, or at rest.

The reasoning is the same for fig. 8 and 9, or any other position of the glasses, provided they are parallel to each other when the index is at the beginning of the degrees on the limb of the quadrant.

If the quadrant liberates sideways, or has a motion contrary to the former, there will, indeed, be a motion of the image produced, because since the image is always formed in the plane of reflection, which passes through the object and the eye of the observer, it is evident if that plane be changed, the place of the image must change with it, and a motion of the image will be the effect of such a motion of the instrument; but then this motion is so far from being detrimental, that, on the contrary, it is of very great use in many cases, which expert observers are well acquainted with.

The preceding particulars are the *most essential* which constitute the nature and theory of this capital instrument; more minute mathematical inquiries may be found in the publications on the instrument by *Ludlam*, *Magellan*, and others; and many useful practical remarks by the same authors in *Maskelyne's Mariner's Guide*, and the *Requisite Tables*.

A Table

A Table of the Refraction of the Heavenly Bodies, to be subtracted from the observed Altitude.

Elevation of the Eye above the Sea in Feet.	Dip of the Horizon of the Sea.												
		App. Alt.	Refrac.	App. Alt.	Refrac.	App. Alt.	Ref.	App. Alt.	Ref.	App. Alt.	Ref.	App. Alt.	Ref.
		° ' "	° ' "	° ' "	° ' "	° ' "	° ' "	° ' "	° ' "	° ' "	° ' "	° ' "	° ' "
1	0 57	0	33 0	4 50	10 11	10 30	5 0	26 0	1 56	59 0	0 34		
2	1 21	5	32 10	5 0	9 54	10 45	4 53	27	1 51	60	33		
3	1 39	10	31 22	5 10	9 38	11 0	4 47	28	1 47	61	32		
4	1 55	15	30 35	5 20	9 23	11 15	4 40	29	1 42	62	30		
5	2 00	20	29 50	5 30	9 8	11 30	4 34	30	1 38	63	29		
6	2 20	30	28 22	5 40	8 54	11 45	4 29	31	1 35	64	28		
7	2 31	32	28 5	5 50	8 41	12 0	4 23	32	1 31	65	26		
8	2 42	36	27 30	6 0	8 28	12 20	4 16	33	1 28	66	25		
9	2 52	40	27 0	6 10	8 15	12 40	4 9	34	1 24	67	24		
10	3 1	50	25 42	6 20	8 3	13 0	4 3	35	1 21	68	23		
12	3 18	1 0	24 29	6 30	7 51	13 20	3 57	36	1 18	69	22		
14	3 34	1 10	23 20	6 40	7 40	13 40	3 51	37	1 16	70	21		
16	3 49	1 20	22 15	6 50	7 30	14 0	3 45	38	1 13	71	19		
18	4 3	1 30	21 15	7 0	7 20	14 20	3 40	39	1 10	72	18		
20	4 16	1 40	20 18	7 10	7 11	14 40	3 35	40	1 8	73	17		
22	4 28	1 50	19 25	7 20	7 2	15 0	3 30	41	1 5	74	16		
24	4 40	2 0	18 35	7 30	6 53	15 30	3 24	42	1 3	75	15		
26	4 52	2 10	17 48	7 40	6 45	16 0	3 17	43	1 1	76	14		
28	5 3	2 20	17 4	7 50	6 37	16 30	3 10	44		59 77	13		
30	5 14	2 30	16 24	8 0	6 29	17 0	3 4	45		57 78	12		
35	5 39	2 40	15 45	8 10	6 22	17 30	2 59	46		55 79	11		
40	6 2	2 50	15 9	8 20	6 15	18 0	2 54	47		53 80	10		
45	6 24	3 0	14 36	8 30	6 8	18 30	2 49	48		51 81	9		
50	6 44	3 10	14 4	8 40	6 1	19 0	2 44	49		49 82	8		
60	7 23	3 20	13 34	8 50	5 55	19 30	2 39	50		48 83	7		
70	7 59	3 30	13 6	9 0	5 48	20 0	2 35	51		46 84	6		
80	8 32	3 40	12 40	9 10	5 42	20 30	2 31	52		44 85	5		
90	9 3	3 50	12 15	9 20	5 36	21 0	2 27	53		43 86	4		
100	9 33	4 0	11 51	9 30	5 31	21 30	2 24	54		41 87	3		
		4 10	11 29	9 40	5 25	22 0	2 20	55		40 88	2		
		4 20	11 8	9 50	5 20	23 0	2 14	56		38 89	1		
		4 30	10 48	10 0	5 15	24 0	2 7	57		37 90	0		
		4 40	10 29	10 15	5 7	25 0	2 2	58		35			